EFFORTFUL CONTROL MODERATES THE ASSOCIATION BETWEEN EMOTIONAL INSTABILITY AND BINGE EATING

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

We hypothesized that (H1) emotional instability would be associated with an increased likelihood of a binge episode, and that (H2a) this relationship would be potentiated among individuals with low cognitive control and (H2b) high behavioral impulsivity. Methods: Participants were 48 community-dwelling adults and college students. Participants completed the stroop task (cognitive control) and stop signal task (behavioral impulsivity), followed by two weeks of Ecological Momentary Assessment (EMA) examining mood, hunger, and binge eating behavior up to 9 times per day. Results: There was no main effect of emotional instability on the likelihood of a binge outcome (H1 unsupported). Consistent with H2a, participants with lower cognitive control were more likely to binge as emotional instability increased (OR = .9899, p = .006). Counter to H2b, participants with higher behavioral impulsivity (stop signal scores) were less likely to binge as emotional instability increased (OR = .9916, p = .029).

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LIST OF ABBREVIATIONS

BN ....Bulimia Nervosa

BED.......................................Binge Eating Disorder

DSM ....Diagnostic and Statistical Manual of Mental Disorders

BMI ....Body Mass Index

EMA......................................Ecological Momentary Assessment

MSSD....................................Mean Square of Successive Differences

SD ....Standard Deviation

ROS.......................................Regions of Significance

OR ....Odds Ratio

INTRODUCTION

Binge Eating

According to the most current edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5; American Psychiatric Association, 2013), binge eating is defined as: "Eating, in a discrete period of time (e.g., within any 2-hour period), an amount of food that is definitely larger than what most individuals would eat in a similar period of time under similar circumstances and is characterized by a sense of lack of control over eating during the episode". Binge eating serves as an essential diagnostic criterion for both Bulimia Nervosa (BN) and Binge Eating Disorder (BED). One large-scale, longitudinal study on nearly 500 female adolescents in the U.S. from age 12 to age 20 found point prevalence rates for all clinical and subthreshold eating disorders to be 13.1%, with 2.6% and 3% for clinical BN and BED. Alarmingly, an additional 4.4% and 3.6% of girls developed subthreshold BN and BED (respectively) by age 20, and the authors found that almost a third of subclinical cases of BN and BED progressed to clinical eating disorders during the course of the 8-year study. In contrast, the progression rate from subthreshold to clinical anorexia nervosa was 0%, suggesting that the engagement in binge eating behavior may be more prone to escalation after onset (Stice, Marti, & Rohde, 2013).

Pathological eating is associated with detriments to emotional and physical health. In the above longitudinal study, the authors found that those suffering from subthreshold and clinical eating disorders also reported more functional impairment, distress, mental health treatment, and suicidality (Stice et al., 2013). Unsurprisingly, BED is also linked to an increased risk of obesity (Crow, Kendall, Praus, & Thuras, 2001). As such, BED is associated with many of the same outcomes as obesity. However, controlling for body mass index (BMI), Reichborn-Kjennerud et al. (2003) found that BED was associated with an increase in alcohol problems, use of pain medication, smoking and decreased exercise *in men only.* In women, ill effects on physical health were no longer significant after controlling for obesity. Although these results are preliminary, this difference is quite concerning when considering the lack of male participation in studies researching the effects and development of BED.

Negative Reinforcement Model

A popular theory in the binge eating literature is the negative reinforcement affect regulation model (Hawkins & Clement, 1984), which posits that people binge eat because of increased negative affect, which decreases after binge eating, thus reinforcing this behavior. There is widespread support for the finding that binge-eating episodes are triggered by negative affect (Agras & Telch, 1998; Alpers & Tuschen-Caffier, 2001; Chua, Touyz, & Hill, 2004; Greeno, Wing, & Shiffman, 2000; Lynch, Everingham, Dubitzky, Hartman, & Kasser, 2000). Studies disaggregating negative mood into subcomponents have found that anger/hostility, stress, and general negative affect predict binge eating (Smyth et al., 2007). Increases in guilt are strongly predictive of bingeing, and in one study it was the only form of negative affect that remained significant after controlling for fear, hostility and sadness (K. C. Berg et al., 2013).

Research analyzing the second essential component of the negative reinforcement affect regulation model has produced slightly less consistent results. A number of studies have found that negative affect does significantly decrease following a binge episode (Agras & Telch, 1998; De Young et al., 2013; Ranzenhofer et al., 2013; Smyth et al., 2007), but these findings are not unanimous. One study that measured anxiety both physiologically and by self-report found that bingeing did not reduce anxiety (Jensen, 1997) and another study found that negative affect actually *increased* following binge episodes, but decreased upon compensation (Lynch et al., 2000). Goldschmidt et al. (2012) found that patients with binge eating disorder (BED) experienced an increase in negative affect following a binge, as opposed to obese controls, who experienced a decrease. An oft-cited meta-analysis of ecological momentary assessment (EMA) studies concluded that negative affect may actually increase following a binge, rather than decrease (Haedt-Matt & Keel, 2011). However, K. C. Berg et al. (2014) conducted another study to more closely examine the methodology employed in most EMA studies of binge eating. Their results, presented at the International Conference on Eating Disorders in 2014, revealed that most post-binge signals occur very closely following the actual binge event, while most pre-binge signals occur an hour or more before the binge event. Post-binge assessments that are immediately following a binge do not capture the decline in negative affect that follows over the next hour or two, and thus overestimates the negative affect post-binge. The authors suggest that this pattern could be responsible for some studies' findings that negative affect may actually increase following a binge.

Loss of Control

Herman's Restraint Theory (1975) posits that cognitive processes, combined with mood, are responsible for regulating food intake. Research using cross-sectional data (Colles, Dixon, & O'Brien, 2008; Goldschmidt et al., 2008) and even EMA (Pollert et al., 2013) has shown that loss of control is strongly correlated with binge eating. Thus, this serves as an essential criterion in the definition of binge eating in the *Diagnostic and*

Statistical Manual of Mental Disorders (American Psychiatric Association, 2013). In restrained eaters, negative affect may trigger loss of cognitive control over eating, which has been shown to lead to cravings (Hepworth, Mogg, Brignell, & Bradley, 2010) and disinhibited binges (Chua et al., 2004). Studies have found that loss of control, rather than quantity of food consumed, is the essential factor of a subject-defined binge episode (Goldschmidt et al., 2012; Pollert et al., 2013).

Emotional Instability

Although the roles of precipitant negative affect and loss of control on binge eating are relatively clear, only a few studies have analyzed how emotional fluctuations throughout the day may predict binge episodes. Emotional instability is correlated with a variety of disinhibited behaviors, including alcohol problems (Stevenson, Dvorak, Kuvaas, Williams, & Spaeth, 2015), poor performance on emotionally potent response inhibition ("go/no-go") tasks (Lee, Turkel, Woods, Coffey, & Goetz, 2012), and binge eating (Benjamin & Wulfert, 2005). One ecological momentary assessment (EMA) study of bulimic individuals with borderline personality disorder found that emotional instability was higher on days with self-reported binge/purge episodes than on days without bulimic events (Selby et al., 2012) and another found that variability of negative mood predicted overall number of binges throughout a two-week EMA study (Yu & Selby, 2013).

Resource Model of Self-Control

According to the resource model of self-control (Baumeister, Heatherton, & Tice, 1994), individuals who deplete self-control resources while attempting to regulate their emotions will lack enough remaining self-control to resist subsequent temptations, and thus, they will be more prone to impulsive behaviors such as binge eating. In a carefully controlled series of experiments by Bruyneel, Dewitte, Franses, and Dekimpe (2009), subjects who were induced to feel negative mood and subsequently allowed to self-regulate their emotions consistently bet more money on a gambling task. In another experimental test of the resource model, Hartmann, Rief, and Hilbert (2013) found that adolescents who engage in loss-of-control eating experienced greater decreases in performance on the stop signal task after a negative mood induction, as compared to healthy controls. The theory also posits that an individual’s ability to exert self-control resources may increase with repeated use, somewhat analogous to a muscle. Oaten and Cheng (2006) found that participants’ self-control depletion decreased after a study program intervention designed to increase their baseline resources with repeated practice. The participants in this study reported engaging in less chemical use (caffeine, alcohol, cigarettes), exercising more and longer, eating more healthily, regulating emotions more successfully, and completing chores more regularly after the intervention.

These findings, coupled with recent research showing that behavioral control (as measured by the stop signal task) appears to be impaired in patients with BED as compared to healthy controls (Svaldi, Naumann, Trentowska, & Schmitz, 2014), suggest that individuals who binge eat may have fewer self control resources at baseline. Therefore, they may be more influenced by depletion of those resources when regulating emotions.

These studies demonstrate the potential for emotional instability to restrict an individual’s available self-control resources, increasing the probability for binge eating only for those who lack sufficient resources to manage this deficit. Although this moderation hypothesis has not yet been tested for eating disorder outcomes, a similar link has been found in the substance use literature. In one study, cognitive control, as measured by the stroop task, moderated the relationship between emotional instability and alcohol dependence symptoms (Stevenson et al., 2015). In an EMA study, Muraven, Collins, Shiffman, and Paty (2005) found that self-control demands throughout the day led to greater likelihood of drinking, violating one's own drinking limit, and greater intoxication, and this relationship was moderated by trait self-control, such that those with greater self-control were less influenced by self-control demands throughout the day. Similarly, Gailliot and Baumeister (2007) found that individuals with lower self-control were just as likely to engage in disinhibited sexual behavior as those who had experienced a depletion in self-control resources.

Hypotheses

This study aims to investigate the relationship between emotional instability and binge eating behaviors, as well as the moderating effects of cognitive control and behavioral impulsivity. We hypothesize that (H1) participants will be at increased risk for binge eating on days when they experience increased emotional instability, and (H2a) this effect will be exaggerated in those with lower cognitive control (as measured by the stroop task) and (H2b) this effect will be exaggerated in those with more behavioral impulsivity (as measured by the stop signal task).

METHOD

Procedure

Subjects participating in this study completed three phases. During Phase I, participants were screened for eligibility to complete Phase II (a laboratory session and comprehensive clinical interview). The first 50 eligible participants were selected for Phase III (the EMA phase).

Phase I. Participants (both community members and students) completed an online screening to determine if they were eligible for the EMA portion of the study. Participants reported demographic information, including age, sex, sexual orientation, education level, and ethnicity. Participants were also asked to complete the EDE-Q (Fairburn & Beglin, 2008) during this phase. Subjects that reported at least one objective binge episode per week (measured as four binges over the last 28 days) were eligible to move to Phase II and contacted via email or phone, according to the participant's indicated preference. All participants were entered into a drawing for one of four $50 gift cards. Students could also earn course credit for completing the online screening.

Phase II. Participants who met initial inclusion criteria during Phase I received a clinical interview (see measures). Those meeting full criteria for Anorexia Nervosa were referred for treatment (excluded from study; $n = 1$). Participants then completed the stroop task and stop-signal task (Logan, Schachar, & Tannock, 1997) to measure behavioral control and received training on the use of their personal data device (PDD), to move on to Phase III. At the conclusion of participation, participants were provided with diagnostic feedback and were given a list of local resources for support.

Phase III (EMA Phase). Participants who met full inclusion criteria (*n* = 50) were in enrolled in Phase II, during which they carried a PDD for two weeks, returning to the lab to check-in after one week to ensure compliance with assessments. Participants were paid $25 upon week one completion, and the other $25 upon returning the PDD at the end of the two-week period.

Participants were signaled by nine stratified random assessments throughout each day. Each was scheduled to alert the participants to complete the assessment at a random point within a two-hour period. Time periods started at 8 A.M. and ended at 2 A.M. the following day, such that a random assessment was signaled at some point between 8 A.M. and 10 A.M., and again between 10 A.M. and 12 P.M., etc. Participants were able to delay the alert for up to 10 minutes, after which the assessment expired. Random signals assessed current mood and occurrence of a subjective or objective binge episode since the last completed assessment (see Appendix).

After completing two weeks of EMA data recording, participants returned their devices and came back for one last assessment. They received diagnostic feedback, information on local resources for support, and their final $25. During this meeting, participants were also asked to describe the qualitative aspects of their most recent binge episode (that happened during the study), including portion sizes, food types, and the amount of time taken to consume the food. This measure was included to ensure that participants' personal definitions of a binge episode aligned with clinical criteria. From these reports, we calculated our best estimates of the approximate caloric value of each binge using nutritional data found in simple Internet searches.

Participants

Fifty participants participated in Phase III of the study, but two were excluded from analyses due to endorsing no binge episodes (*n* = 1) and low compliance (14%; *n* = 1). The final sample consisted of 48 participants, 75% of which were female (see Table 1 for more participant characteristics). The large majority of the sample identified as exclusively White (85%); 3 as White mixed with another race (6.25%), 2 as Asian (4%), 2 as Hispanic (one mixed; 4%), and 2 as African American (one mixed; 4%). Twenty seven percent of the sample (*n* = 13) was community-recruited (i.e., not students or employees of the university). Although the SCID used in this study was based on DSM-IV-TR criteria, the interviews provided sufficient data to determine a diagnosis based on DSM-5 criteria as well. Sixty-three percent of participants (*n* = 30) met criteria for BED and 15% (*n* = 7) met criteria for BN according to DSM-5 standards, and the remaining *n* = 11 still endorsed binge eating at least once per week, but did not endorse the requisite distress or impairment to meet full criteria for BED. Participants received information on the potential risks and benefits of participation in the study, provided informed consent, and were treated in accordance with the American Psychological Association's ethical guidelines.

Table 1
Summary of participant characteristics.

	Women (n = 36)			Men (n = 12)		
	Mean	SD	Range	Mean	SD	Range
Age	22.69	4.79	18-34	26.92	8.64	18-41
BMI	28.80	7.89	19.73-51.30	35.98	13.82	21.06-74.99
Number of DSM-IV Axis I Diagnoses*	2.34	1.63	0-6	2.27	1.74	0-5
Daily Response Rate	59.48%	23.07	0-100%	73.46%	21.37	11.21-100%
Binge Calories	2,342	1,352	645-6,000	3,537	3,583	1,030-13,840
Number of Binges	10.44	8.12	0-28	14.5	8.66	3-28

Note. Eating disorders were assessed using DSM-5 criteria. Binge calories based on self-reported binges at study termination (see Phase III for more detail).

Level 1 Measures

This study used ecological momentary assessment (EMA) to assess variables in real time. EMA is particularly well suited to capture binge events because this technique measures mood and behaviors as they are happening in the natural setting, and eliminates retrospective recall biases associated with traditional questionnaires. Level 1 measures were completed on lab-provided personal data devices (PDDs; Samsung Galaxy 4 phones) during Phase III.

***In situ* eating assessments.** Participants indicated whether or not they had eaten since the last assessment (see Appendix). An affirmative response lead to binge eating assessment items, which were adapted from the EDE-Q (Fairburn & Beglin, 2008) to be applicable for an *in situ* assessment. These items were intended to assess subjective binge episodes and the objective overeating component to binge eating, but the subjective item ("Did you have a sense of having lost control over your eating [at the time that you were eating]?") served independently as this study's measure of binge eating. We defined binge eating by loss of control in light of research that indicates that subjective binges are just as clinically relevant to BED and BN as objective binge episodes (Birgegård, Clinton, & Norring, 2013; Brownstone et al., 2013; Niego, Pratt, & Agras, 1997) and that loss of control, the common factor to both subjective and objective binges, is the defining feature of binge eating (Colles et al., 2008). We defined a binge episode as a positive response to the loss of control question.

Hunger was also measured during the eating assessments on a scale from 1 (*very slightly or not at all*) to 5 (*extremely*). Hunger was calculated as the average of a person's hunger ratings either before a binge occurred (on binge days) or before the sample's average binge time (6pm) on non-binge days. As such, this variable could also be indicative of the extent to which an individual had restricted their food intake before 6pm or binge time.

***In situ* mood assessments.** During the EMA portion of this study (Phase III), participants completed 21 items from the PANAS-X and Larsen and Diener (1987)'s mood circumplex in each mood assessment. These items were chosen for their utility in assessing mood in past EMA studies (K. C. Berg et al., 2013; Dvorak, Pearson, & Day, 2014). There are three items in this survey representing each of the following emotions: stress (α = .86), anxiety (α = .79), guilt (α = .92), anger (α = .78), sadness (α = .89), positive affect (α = .86), and calmness (α = .90; see Appendix). Participants responded to questions assessing current mood states (ex: "How CALM are you feeling right now?") on the scale used in the PANAS, rated from 1 (*very slightly or not at all*) to 5 (*extremely*).

In addition to serving as our mood measurement for emotional instability, these mood assessments were used to calculate two very important control variables: average pre-binge positive and negative mood. Average positive mood was based off of the three positive affect questions. Average negative mood was calculated from all of the negative mood subscales: sadness, anger, guilt, stress, and anxiety (α = .92).

Emotional Instability. Examining intraindividual mood variability within discrete days has presented many EMA researchers with methodological challenges. Some studies have successfully used intraindividual standard deviation of negative affect to measure emotional variability (e.g., Weinstein, Mermelstein, Shiffman, & Flay, 2008), and this technique has been found to possess acceptable reliability and validity (Eid & Diener, 1999), but this method is not ideal as it fails to detect intensity of fluctuations. We used mean square of successive differences (MSSD) to assess emotional instability, as suggested by Jahng, Wood, and Trull (2008). MSSD (see below for computation) captures a complete picture of emotional variability, including the frequency and intensity of emotions, as well as their place in time (Ebner-Priemer & Trull, 2009). Since we were interested in overall emotional variability as experienced by the individual, we used one combined MSSD variable as our indicator of emotional instability. Instability was calculated individually for each mood (i.e., guilt, sadness, etc.) and then they were averaged together to represent general mood instability (α = .64).

Level 2 Measures

Participants completed level 2 measures either during the online screening (during Phase I) or in the laboratory setting (during Phase II), for those who were eligible. These measures were considered 'trait-like' characteristics that vary between subjects but not within subjects.

Stop signal task. During the stop signal task, participants view a succession of left- or right-pointing arrows and are instructed to press the corresponding key on a standard keyboard, the 'E' (for left) or the 'I' (for right). On 25% of trials, a stop signal (a brief monotone sound) is presented, which indicates that participants should inhibit their response. Stop signals are not presented simultaneously with the original arrow stimulus, but are instead presented between 50 and 1150 milliseconds (ms; so between .05 and 1.15 seconds) after the arrow, starting at 250 ms (.25 seconds). The task adjusts according to participants' performance. Participants completed one practice block of 32 trials followed by four test blocks of 64 trials each, with breaks in between, during which participants may view their number of errors and reaction time. Stop-signal tasks were designed to measure control (Logan & Cowan, 1984), have been successfully used in interventions to reduce consumption of unhealthy foods (Houben, 2011; Veling, Aarts, & Stroebe, 2013), and served as a measure of behavioral control in this study.

Stroop task. We used the classic color–word Stroop task as a computer-based measure of cognitive control. Subjects must quickly indicate the color of a text prompt, ignoring what the text actually says. In incongruent trials, the color of the text (e.g., red) conflicts with the word that the text spells (e.g., green). In congruent trials, the color and the word match. In control trials, participants indicated the color of a solid rectangle. The first 15 trials were practice, and were excluded from our analyses. Trials with responses that were less than 100 ms or greater than 2000 ms were also excluded from our analyses. Analyses included 72 test trials per participant, which included an even distribution of congruent, incongruent, and control trials. Considerable research supports the use of the Stroop task as a measure of cognitive control (MacLeod, 1991). There was a reliable Stroop effect, such that congruent trials (M = 744.35, SD = 132.96, range = 510.08–1,221.68) showed faster reaction times than incongruent trials (M = 795.39, SD =

145.33, range = 569.85–1,226.32), $t(47) = -6.29$, $p < .001$, Cohen's $d = .908$. Split-half reliability was assessed using the Spearman-Brown correlation, and was acceptable for both congruent trials ($r_{sb} = .88$) and incongruent trials ($r_{sb} = .89$).

Eating Disorder Examination Questionnaire (EDE-Q) 6.0. The EDE-Q is a self-report measure developed from the Eating Disorder Examination (EDE), the gold standard interview for assessing eating disorders symptoms (Fairburn & Beglin, 2008). The EDE-Q contains three questions that pertain specifically to binge-eating behaviors, one of which was used as an inclusion criterion for participation, slightly altered to indicate binge *epsiodes*, rather than days, per DSM-5 criteria. The updated question reads, "Over the past 28 days, how many such episodes of overeating have occurred (i.e., you have eaten an unusually large amount of food and have had a sense of loss of control at the time)?" Participants must have answered indicating that at least four objective binge episodes occurred over the last 28 days (one binge/week) to qualify for participation in Phase II of the study. Retrospective EDE-Q reports of frequency of binge eating behaviors have been found to correlate significantly with subsequent daily diary reports of the same behaviors (Grilo, 2001).

Structured Clinical Interview for DSM-IV research version for non-patients (SCID-I/NP). The SCID-I/NP is a diagnostic interview designed for use in research settings. This version of the SCID detects a variety of Axis I disorders, including Bulimia Nervosa (BN), Anorexia Nervosa (AN), and Binge-Eating Disorder (BED). Inter-rater reliability for the eating disorders portions of the SCID-I is good, ranging from inter-rater $\kappa = .61$ (Lobbestael, Leurgans, & Arntz, 2011) to .77 (Zanarini et al., 2000). Test-retest reliability was also found to be acceptable ($\kappa = .64$; Zanarini et al., 2000). The first author (B.S.) administered all SCID interviews under supervision of the second author (R.D.).

Data Analysis Plan

Power analysis. A Monte Carlo simulation for a multi-level model was performed in Mplus 7.11, assuming 14 days of within-subject monitoring and two binges during this time (based on inclusion criteria). A meta-analysis of EMA and diary studies by Haedt-Matt and Keel (2011) found that the mean weighted effect size for negative affect before a binge episode, as compared to general negative affect, was .63. As emotional instability is highly correlated with negative affect (Dizén & Berenbaum, 2011; Wei, Vogel, Ku, & Zakalik, 2005), we used this as an estimate of effect for the emotional instability variable. The results of this analysis suggested that 46 participants would be needed to provide 84% coverage of significant effects for H2 (at this *n,* the coverage for a significant H1 parameter, assuming *r* = .64 effect size, was 100%). We aimed to recruit *n* = 50 to allow for a 9% attrition rate.

Computation of MSSD. As mentioned above, MSSD is a measure of emotional instability that captures the frequency, intensity and temporal placement of the variations in each participant's reported emotions (Jahng et al., 2008). The computation for MSSD is as follows: $MSSD = \frac{1}{N-1}\sum_{i=1}^{N-1}(x_{i+1} - x_i)^2$. Since we are interested in emotional variations leading up to a binge episode, emotional instability for each day was calculated up until the first binge episode occurred, or until 6pm (the average time of first binge) if no binge episode was reported that day. If multiple binge episodes occurred in one day, only the emotional variability leading up to the first binge was calculated.

Model Estimation. The analysis utilized a multilevel logistic modeling approach. The outcome was defined as 0 = no binge that day, 1 = the day included a binge. The analysis was conducted in HLM 7 (Raudenbush, Bryk, & Congdon, 2005) with robust standard errors. At level 1, all variables were person-centered. At level 2, all variables were grand-mean centered. Statistically significant cross-level interactions were probed at +/- 1 SD and regions of significance for each interaction were calculated.

RESULTS

EMA Assessment and Compliance Statistics

The final dataset consisted of 709 person days. Participants endorsed a subjective binge on 361 days (51% of total days), however, we were only able to calculate emotional instability for 464 days, 217 of which included a binge, since a minimum of two completed surveys were required before a binge. There were a total 5,941 random assessment prompts, 3,687 of which were completed (compliance = 62%). On average, participants completed 5.42 random surveys a day.

Descriptive Statistics

Bivariate correlations for study variables are displayed in Table 2. Age was inversely correlated with sex and positively correlated with BMI. Men had higher BMI scores than women. There was an inverse correlation between mean levels of hunger and BMI. Number of binges was positively correlated with mean negative mood. Positive mood was inversely correlated with both behavioral impulsivity (stop-signal scores) and negative mood. Mean emotional instability was positively correlated with mean levels of negative mood, and inversely correlated with cognitive control (stroop interference scores). Stop signal scores ranged between 73.93 and 301.80 (*M* = 181.16, *SD* = 47.88) and stroop interference scores ranged between -163.25 and 55.91 (*M* = -51.04, *SD* = 56.22).

Table 2
Pairwise correlations between study variables.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1. Age	--	**-.30***	-.18	**.57§**	.01	-.15	-.06	-.24	.19	.03
2. Sex		--	.10	**-.31***	-.21	-.06	-.14	.04	-.03	.27
3. Hunger			--	-.11	**-.48§**	-.08	-.26	-.19	.19	.06
4. BMI				--	.15	.13	.06	-.04	-.13	.08
5. Number of binges					--	.06	.18	**.31***	-.14	-.01
6. Stroop						--	.04	-.15	-.13	**-.47***
7. Stop Signal							--	.29	**-.33***	.13
8. Negative Mood								--	**-.43§**	**.49***
9. Positive Mood									--	-.16
10. Emotional Instability										--

Note. Sex was coded as 0 = male, 1 = female (an 'other' category was included, but no participants endorsed this option). Hunger and all mood variables were calculated pre-binge on binge days or before 6pm on non-binge days. Emotional instability is the average of each person's emotional instability throughout the whole study. Bolded correlations are statistically significant; $^{*}p < .05$, $^{\S}p < .001$.

Multilevel Logistic Analysis

To examine the effects of emotional instability throughout the day on the likelihood of a binge episode for individual *i* at time *t*, controlling for each individual's average pre-binge positive and negative mood, the following level 1 equation was specified:

$$Prob(Binge\ Episode_{ti}) = \pi_{0i} + \pi_{1i}*(Average\ Pre\text{-}binge\ Positive\ Mood_{ti}) + \pi_{2i}*(Average\ Pre\text{-}binge\ Negative\ Mood_{ti}) + \pi_{3i}*(Pre\text{-}binge\ Emotional\ Instability_{ti}) + \pi_{4i}*(Hunger_{ti}) + e_i$$

Level 1 variance components for the intercept and slope were evaluated. The intercept contained a significant random variance component ($\sigma^2 = 1.80$, $p < .001$; $\alpha = .73$) and was allowed to vary randomly; the slope did not, and thus the variance component was fixed to zero. In each equation, we controlled for Gender, Age, and BMI. To examine the effects of behavioral and cognitive control on the binge episode intercept and the emotional instability slope, the following level 2 equations were specified:

$$\pi_{0i} = \beta_{00} + \beta_{01}{*}(Gender_i) + \beta_{02}{*}(Age_i) + \beta_{03}{*}(BMI_i) + \beta_{04}{*}(Stop\ Signal_i) + \beta_{05}{*}(Stroop_i) + r_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11}{*}(Gender_i) + \beta_{12}{*}(Age_i) + \beta_{13}{*}(BMI_i) + \beta_{14}{*}(Stop\ Signal_i) + \beta_{15}{*}(Stroop_i)$$

$$\pi_{2i} = \beta_{20} + \beta_{21}{*}(Gender_i) + \beta_{22}{*}(Age_i) + \beta_{23}{*}(BMI_i) + \beta_{24}{*}(Stop\ Signal_i) + \beta_{25}{*}(Stroop_i)$$

$$\pi_{3i} = \beta_{30} + \beta_{31}{*}(Gender_i) + \beta_{32}{*}(Age_i) + \beta_{33}{*}(BMI_i) + \beta_{34}{*}(Stop\ Signal_i) + \beta_{35}{*}(Stroop_i)$$

$$\pi_{4i} = \beta_{40} + \beta_{41}{*}(Gender_i) + \beta_{42}{*}(Age_i) + \beta_{43}{*}(BMI_i) + \beta_{44}{*}(Stop\ Signal_i) + \beta_{45}{*}(Stroop_i)$$

A statistically significant positive coefficient for $\pi_{1i}{*}(Emotional\ Instability_{ti})$ in the level 1 equation would indicate support for Hypothesis 1. A statistically significant positive coefficient for $\beta_{35}{*}(Stroop_i)$ or $\beta_{34}{*}(Stop\ Signal_i)$ in the Level 2 equation would indicate support for Hypothesis 2a or Hypothesis 2b, respectively. These coefficients represent the cross-level interactions between within-subject mood instability and between-subject cognitive control and behavioral impulsivity.

Hunger

Binge episodes became more likely as participant hunger increased, OR = 1.34, $p = .024$ (see Table 3 for a summary of the main effects). There was an interaction with behavioral impulsivity, such that those with higher impulsivity were more likely to binge as hunger increased OR = 1.01, $p = .006$. We probed the interaction at +/-1 *SD* on stop signal scores. At -1 *SD*, the interaction is not significant (p = .820), but individuals with a stop signal score that is +1 *SD* were 89% more likely to binge as hunger increased by one unit, OR = 1.89, p < .001 (see Figure 1). A regions of significance (ROS) analysis revealed that the cut-off score was 175.15 (*SD* = -0.13), such that individuals with a stop signal score above *SD* = -.013 were significantly more likely to binge as hunger increased.

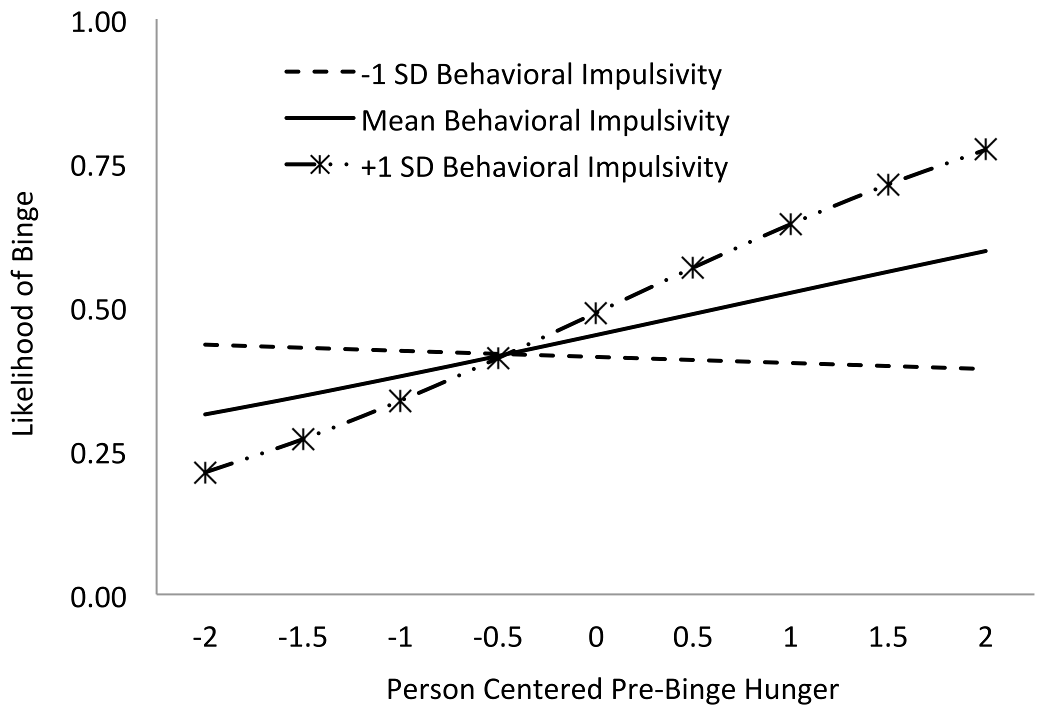

Figure 1. Effect of hunger on likelihood of a binge at high and low stroop scores (cognitive control).

Table 3
Multilevel models predicting binge likelihood.

Predictor Variables	Level	Binge Likelihood (OR)[1]	*p* value
Intercept	1	0.820	.347
Age	2	0.968	.452
Sex	2	0.475	.120
BMI	2	1.013	.621
Cognitive Control	2	1.001	.839
Behavioral Impulsivity	2	1.003	.478
Hunger	1	1.343	.024
Age	2	1.050	.096
Sex	2	1.344	.262
BMI	2	1.000	.988
Cognitive Control	2	1.003	.296
Behavioral Impulsivity	2	1.007	.006
Positive Mood Slope	1	1.170	.480
Age	2	0.923	.102
Sex	2	0.613	.460
BMI	2	1.062	.164
Cognitive Control	2	0.998	.680
Behavioral Impulsivity	2	0.991	.038
Negative Mood Slope	1	3.067	.007
Age	2	0.900	.302
Sex	2	0.849	.853
BMI	2	1.051	.274
Cognitive Control	2	1.002	.701
Behavioral Impulsivity	2	0.985	.042
Mood Instability Slope	1	0.843	.396
Age	2	0.997	.950
Sex	2	0.621	.182
BMI	2	1.022	.597
Cognitive Control	2	0.990	.006
Behavioral Impulsivity	2	0.992	.029

Note. Level 1: Within-subjects effects, centered at subject level. Level 2: Between-subjects effects, centered at grand-mean. n = 48, [1]n = 709 person-days.

Negative Mood

Consistent with much previous literature (Haedt-Matt & Keel, 2011), average pre-binge negative mood strongly predicted the likelihood of a binge episode, OR = 3.07, p = .007. This was moderated by behavioral impulsivity, OR = 0.99, p = .042. Simple slopes revealed that, contrary to what we would have expected, participants at -1 *SD* behavioral impulsivity were 6 times more likely to binge as negative mood increased, OR = 6.22, $p < .001$ (see Figure 2). The slope of negative mood was no longer significant when stop signal was at +1 *SD* (OR = 1.51, $p = .458$). An ROS analysis revealed that participants with stop signal scores below *SD* = 0.38 (52% of our sample) were significantly more likely to binge as negative affect increased.

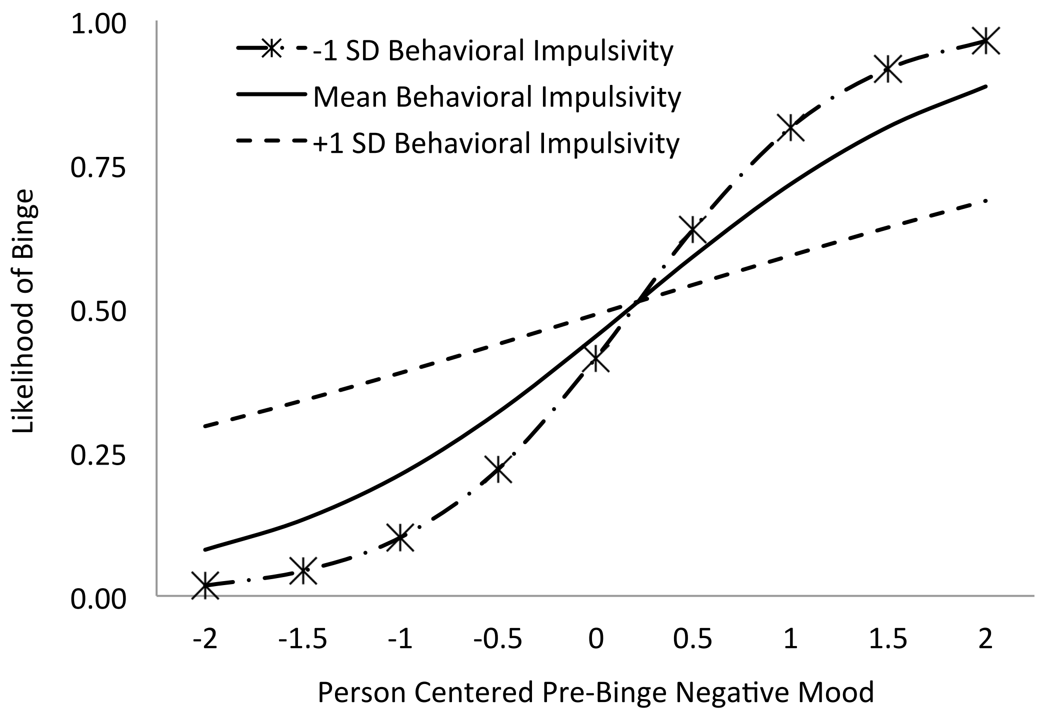

Figure 2. Effect of pre-binge negative mood on likelihood of a binge at high and low stop signal scores (behavioral impulsivity).

Positive Mood

There was no main effect for average pre-binge positive mood on likelihood of a binge episode ($p = .480$). However, an interaction similar to that observed with negative mood was also observed between positive mood and stop signal, OR = 0.99, $p = .038$. Although the relationship was not significant at +1 *SD* ($p = .356$), it was approaching significance at -1 *SD* of stop signal scores, OR = 1.79, $p = .062$. An ROS analysis showed that participants with stop signal scores below *SD* = -1.09 (25% of our sample) were significantly more likely to binge as positive mood increased.

Emotional Instability

There was no main effect for emotional instability on the likelihood of a binge (OR = 0.84, p = 0.396), failing to support Hypothesis 1. However, emotional instability interacted with both cognitive control and behavioral impulsivity to predict binge eating. Consistent with Hypothesis 2a, although framed differently, individuals with higher stroop scores (i.e., higher cognitive control) were less likely to binge as emotions became more variable, OR = .9899, p = .006. At +1 *SD* cognitive control (stroop scores) participants were 52% less likely to binge a function of emotional instability, OR = 0.48, p = .016 (see Figure 3). At -1 *SD*, the slope was not statistically significant (p = .145), but the ROS analysis revealed that participants with cognitive control scores below *SD* = -1.67 (8% of our sample) were significantly more likely to binge as emotional instability increased. The ROS also showed that participants were less likely to binge as a function of increasing emotional instability beginning at just *SD* = 0.50 above the mean (37.5% of our sample).

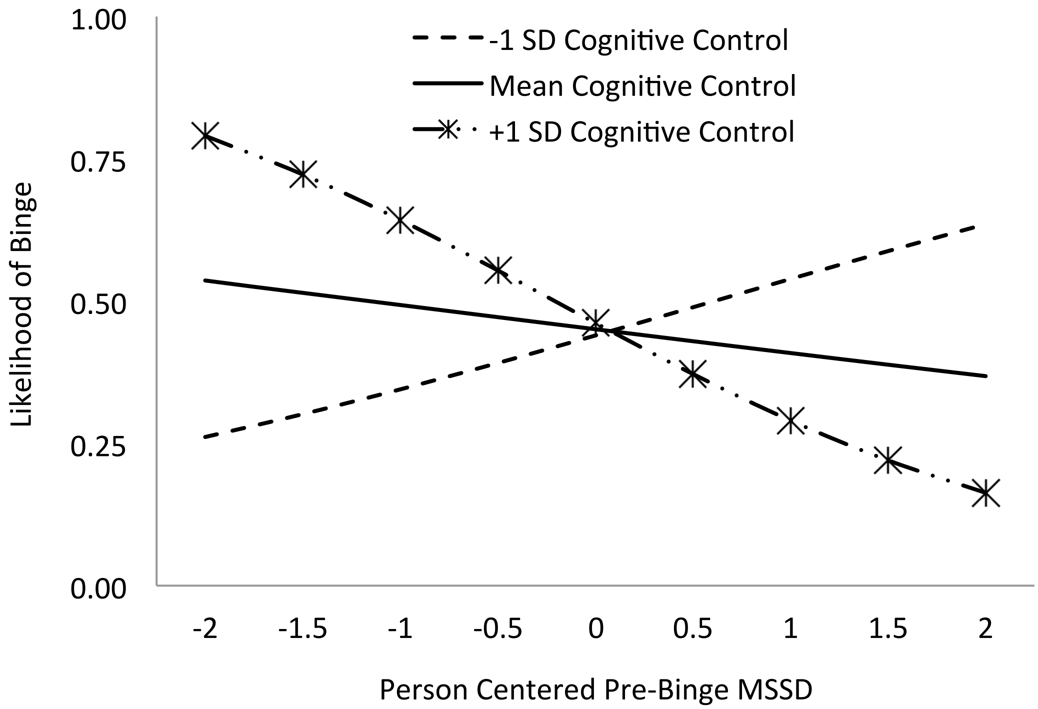

Figure 3. Effect of emotional instability on likelihood of a binge at high and low stroop scores (cognitive control).

Emotional instability also interacted with behavioral impulsivity to predict binge eating, and this interaction contradicted Hypothesis 2. Those with higher behavioral impulsivity (i.e., higher stop signal scores) were less likely to binge as emotional instability increased, OR = 0.99, p = .029. The simple slopes at +/- 1 *SD* and were not statistically significant (p = .058 and p = .331, respectively). The ROS analysis revealed that the centered cut-off value was before +1 *SD*, at *SD* = 0.75, such that anyone whose stop signal score was above *SD* = 0.75 (22.9% of our sample) was less likely to binge as emotional instability increased (see Figure 4).

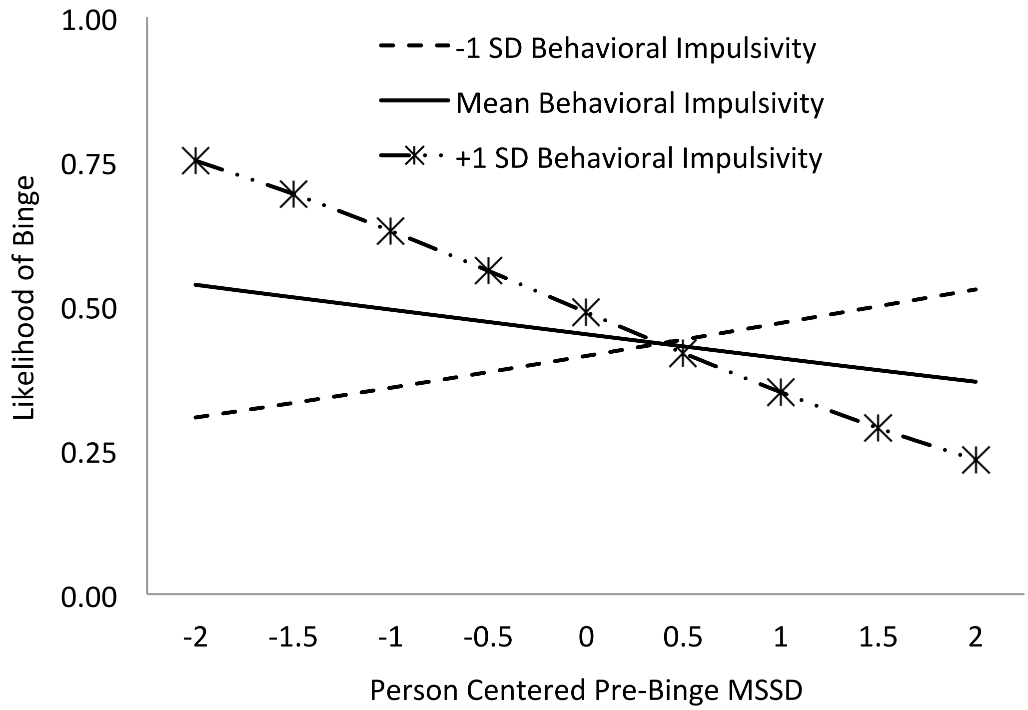

Figure 4. Effect of emotional instability on likelihood of a binge at high and low stop signal scores (behavioral impulsivity).

DISCUSSION

Previous EMA research has found that negative affect precedes binge eating episodes (Haedt-Matt & Keel, 2011) and emotional instability is associated with likelihood of binge eating (Selby et al., 2012). Studies have shown that BED patients also show deficits in behavioral impulsivity (as measured by the stop signal task) compared to healthy controls (Svaldi et al., 2014), suggesting that they may possess fewer resources to control impulsive behavior. Since regulating emotion is an effortful task that depletes self-control resources (Bruyneel et al., 2009), we hypothesized that (H1) emotional instability would lead to an increased likelihood of binge eating, and that this relationship would be moderated by (H2a) high cognitive control (as measured by the stroop task) and (H2b) low behavioral impulsivity (as measured by the stop signal task).

Our first hypothesis was not directly supported. Emotional instability did not directly predict the likelihood of binge eating over and above negative mood, positive mood, and hunger. Our second hypothesis was partially supported. The interaction between emotional instability and stroop scores was consistent with our hypothesis; those with lower stroop scores (lower cognitive control) were more likely to binge as emotional instability increased. However, for the stop signal task, those with higher scores (i.e., higher behavioral impulsivity) were less likely to binge as emotional instability increased. Each of these findings is discussed in greater detail below.

Non-Hypothesized Findings

Consistent with previous literature documenting hunger or caloric restriction as a risk factor for bingeing (Stein et al., 2007; Zunker et al., 2011), hunger was associated with likelihood of a binge, and this effect was exaggerated for those with higher behavioral impulsivity. It is important to note that our binge variable was measured as the presence of loss of control over eating, consistent with current empirical findings (Birgegård et al., 2013; Goldschmidt et al., 2008), regardless of binge size. So, although our subjects did report large binges (*M* calories = 2,654), this association is not between hunger and eating a large amount, per se; it is between hunger and losing control over eating. This finding suggests that hunger may further disinhibit participants who already perform more impulsively on the stop signal task.

Low behavioral impulsivity was associated with an increased likelihood of bingeing as positive mood increased, a finding that raises questions about the role of positive urgency (the tendency to act rashly when very happy) in binge eating. If positive urgency were a factor in influencing binge eating, one would expect that those with *high* behavioral impulsivity would be more likely to binge as positive mood increases. We found the opposite. Although positive urgency has not been frequently researched in relation to binge eating, this finding is consistent with one of the rare studies to examine this association: Cyders and Smith (2007) also found that positive urgency was not related to binge eating.

Hypothesis 1

Previous research has linked emotional instability to binge eating (Benjamin & Wulfert, 2005; Selby et al., 2012; Yu & Selby, 2013). Based on this, we hypothesized that days with higher emotional instability would result in a higher likelihood of a binge. This was not the case, and in fact, there was a negative, though non-significant, association between pre-binge emotional instability and binge likelihood. While a number of EMA studies have examined fine-grained relationships between momentary emotion and binge episodes (e.g., K. C. Berg et al., 2013), studies examining emotional instability so far have examined whole-day emotional instability or used the total number of binges reported as the dependent variable (e.g., Yu & Selby, 2013). Indeed, if we change our emotional instability variable from only pre-binge mood instability to whole-day mood instability, the relationship between emotional instability and binge behavior is very strong, but our goal was not to determine if there was an association between bingeing and emotional instability at the day level. On the contrary, we wanted to determine if emotional variability leading up to a binge episode would predict the likelihood of a binge occurring, which it did not in our sample. Perhaps emotional instability itself is not a good indicator of "negative affect"-driven binge eating, but instead, serves as a mechanism for depleting effortful control mechanisms. This means that any effects of emotional instability on binge behavior would be primarily a function of levels of effortful control, an aspect examined for our second hypothesis.

Hypothesis 2a

Consistent with our second hypothesis, high cognitive control (low stroop scores) predicted a lower likelihood of bingeing as emotional instability increased. This is consistent with previous studies showing that emotional instability is associated with impulsive behavior (Anestis et al., 2009) and eating disorder symptoms in eating disordered individuals (Selby et al., 2012). Ours is the first, to our knowledge, to demonstrate a real-time link between emotional variability and binge eating, as moderated by trait-level effortful control. The fact that there was not a direct positive association between emotional instability and bingeing at mean levels of cognitive control lends credence to the idea that emotional instability may not play a substantial role in the affect regulation model of eating pathology (e.g., Haedt-Matt & Keel, 2011). Instead, emotional instability appears to be more aligned with a resource depletion, and subsequent self-regulation failure, model (e.g., Hartmann et al., 2013).

Hypothesis 2b

Previous research has shown that stop signal task (Svaldi et al., 2014) and stroop task (Manasse et al., 2014) performance are impaired in binge eaters, leading researchers to hypothesize that impaired effortful control plays a role in precipitating and maintaining binge behavior. In our sample, however, high behavioral impulsivity (high stop signal scores) was associated with a lower likelihood of bingeing as emotional instability and negative affect increased. This interaction is surprising, especially in light of recent research reporting that the stop signal task may be most closely related to the impulsivity construct urgency, or the tendency to act rashly when upset (Cyders & Coskunpinar, 2011; Wilbertz et al., 2014), and there is considerable research linking binge eating disorder with increased negative urgency (Cyders & Smith, 2008), even prospectively (Fischer, Peterson, & McCarthy, 2013). Another team of researchers also recently examined the relationship between negative mood over the past week and disordered eating (Davis-Becker, Peterson, & Fischer, 2014). Contrary to their hypotheses, and consistent with our counterintuitive finding, negative urgency did not moderate this relationship. Taken with our findings, this pattern suggests that, although negative urgency is associated with binge eating, it may have little effect on the well-established association between negative mood and bingeing.

It is also possible that the association found in our study may be explained by these individuals engaging in other mood-regulating activities or simply failing to respond to their surveys as emotional instability and negative affect increase, thus giving the illusion that binge eating did not happen. Another possibility is that an individual's performance on response inhibition tasks like the stop signal fluctuate over time, improving when the individual has more self-control resources available, and worsening when their resources have been exhausted. If measured in real time, as emotions are fluctuating, this most proximal measure of self-control may predict binge eating differently. Future studies with the capacity to measure response inhibition in real time may explore this question further.

The fact that our findings from hypotheses 2a and 2b contradicted each other prompts the question, "Are stroop and stop signal measuring the same construct?" A review by Nigg (2000) concluded that the tasks are measuring fundamentally different processes and the two were not correlated in our study, $r = .0431$, $p = .771$. Although both of these tasks require effortful control to suppress an automatic response (Kalanthroff, Goldfarb, & Henik, 2013), the stroop task requires *interference control* (herein referred to as cognitive control) to maintain a speedy reaction time even though there is distracting information that tempts one to respond differently, and the stop signal task requires *behavioral inhibition* (herein referred to as behavioral impulsivity) to suppress an automatic motor response when signaled. These two tasks have also been shown to activate different regions of the brain (Nigg, 2000). More research is needed to reach any definitive conclusions regarding our seemingly contradictory findings.

Strengths and Limitations

Strengths of this study include the elimination of retrospective self-report measures, relying on measurement of emotions and binge eating behavior in real time and behavioral measures in the laboratory, the inclusion of men and community-dwelling adults in our sample, and including control variables such as mean pre-binge negative and positive mood, hunger, and BMI in our analyses.

Limitations include a relatively low compliance rate (*M* = 62%; before 6pm *M* = 58%) and defining effortful control as a static, trait-like characteristic. Future research should attempt to measure effortful control in real-time as a further test of the resource model of self-control, and to improve understanding of how fluctuations in effortful control relate to health behaviors. Response rate could be improved by including the option to complete make-up assessments and/or event-contingent assessments (i.e., instruct participants to complete assessments each time they binge). This study only included randomly timed assessments, a factor which undoubtedly contributed to the lowered response rate. Additionally, our sample was 85% White, so generalizations to individuals of other races should be done with caution.

Lastly, our counterintuitive findings that emotional instability and negative affect are associated with lower likelihood of bingeing at high levels of behavioral impulsivity warrant skepticism. Although no other studies have directly tested this same relationship, this is contradictory to what we predicted based on previous research. More research needs to be done to clarify the nature of these variables in predicting binge eating.

Furthermore, given the counterintuitive results of our study, along with previous research indicating that self-control resources wax and wane as these resources are exhausted and restored, cognitive control and behavioral impulsivity may not represent trait-like, stable characteristics, as we measured them here. Future studies can improve our understanding of the reliability of these constructs and their relationship with health outcomes by measuring them in real time.

Conclusion

This study demonstrates a near real-time link between emotional instability and binge eating, as moderated by effortful control. Specifically, participants with better cognitive control and more behavioral impulsivity were less likely to binge as emotional instability increased. More research is needed to clarify how these different forms of effortful control moderate the relationship between emotional variability and binge eating.

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APPENDIX. *IN SITU* ASSESSMENTS

In Situ Assessment Questions (occur 9 times from 8am to 2am)

Mood Assessment – The next 21 questions will be rated on a scale between 1 (very slightly or not at all) to 5 (extremely).

1. How HAPPY are you feeling right now?
2. How JOYFUL are you feeling right now?
3. How EXCITED are you feeling right now?
4. How NERVOUS are you feeling right now?
5. How JITTERY are you feeling right now?
6. How ANXIOUS are you feeling right now?
7. How STRESSED are you feeling right now?
8. How OVERWHELMED are you feeling right now?
9. How FRAZZLED are you feeling right now?
10. How SAD are you feeling right now?
11. How DOWNHEARTED are you feeling right now?
12. How DEPRESSED are you feeling right now?
13. How CALM are you feeling right now?
14. How RELAXED are you feeling right now?
15. How AT EASE are you feeling right now?
16. How ANGRY are you feeling right now?
17. How FRUSTRATED are you feeling right now?
18. How TENSE are you feeling right now?
19. How ANGRY WITH YOURSELF are you feeling right now?

20. How DISAPPOINTED IN YOURSELF are you feeling right now?

21. How ASHAMED do you feel right now?

Eating Assessment:

1. Have you eaten since your last assessment? (yes, no)
2. How hungry were you when you began eating? (1 = *very slightly or not at all*, 5 = *extremely*)
3. Did you intend to have a meal or just a snack?
4. Would you define what you ate as a binge? (yes, no)
5. Did you have a sense of having lost control over your eating (at the time that you were eating)? (yes, no) [Defines subjective binge]
6. Did you eat what other people would regard as an unusually large amount of food (given the circumstances)? (yes, no) [Defines objective binge]

Emotion Regulation Assessment (rated from 1 = *not at all* to 5 = *completely*)

1. I am having difficulty controlling my behaviors.
2. My emotions feel out of control.
3. I believe that I will continue feeling this way for a long time.